

# HASTELLOY® C-4 Alloy

HASTELLOY C-4 alloy is a nickel-chromium-molybdenum alloy with outstanding high-temperature stability as evidenced by high ductility and corrosion resistance even after aging in the 1200 to 1900°F (649 to 1038°C) range. This alloy resists the formation of grain-boundary precipitates in the weld heat-affected zone, thus making it suitable for most chemical process applications in the as-welded condition. C-4 alloy also has excellent resistance to stress-corrosion cracking and to oxidizing atmospheres up to 1900°F (1038°C).

HASTELLOY C-4 alloy has exceptional resistance to wide variety of chemical process environments. These include hot contaminated mineral acids, solvents, chlorine and chlorine contaminated media (organic and inorganic), dry chlorine, formic and acetic acids, acetic anhydride, and seawater and brine solutions.

Laboratory precipitation studies on C-4 alloy indicate that the intermetallic precipitates (Mu phase) associated with other nickel alloys in the 1200 to 2000°F (649 to 1093°C) temperature range have not been detected. Fine intergranular  $M_6C$  carbides can form but their damaging effect is minimal.

HASTELLOY C-4 alloy can be forged, hot-upset, and impact extruded. Although the alloy tends to work-harden, it can be successfully deep-drawn, spun, press formed or punched. All of the common methods of welding can be used to weld HASTELLOY C-4 alloy, although the oxy-acetylene and submerged arc processes are not recommended when the fabricated item is intended for use in corrosion service. Special precautions should be taken to avoid excessive heat input.

Detailed fabricating information is available in the booklet, "Fabrication of HASTELLOY® Corrosion-Resistant Alloys". Ask for booklet H-2010.

Wrought forms of HASTELLOY C-4 alloy are furnished in the solution heat-treated condition unless otherwise specified. C-4 alloy is solution heat-treated at 1950°F (1066°C) and rapid quenched.

HASTELLOY C-4 alloy plate, sheet, strip, bar, tubing and pipe are covered by ASME specifications SB-574, SB-575, SB-6119, SB-622 and SB-626 under UNS number N06455.

## Nominal Chemical Composition, Weight Percent\*

| Ni              | Co    | Cr            | Mo            | Ti     | Fe    | Si     | Mn    | C      | Others                 |
|-----------------|-------|---------------|---------------|--------|-------|--------|-------|--------|------------------------|
| 65 <sup>a</sup> | 2.0** | 14.0-<br>18.0 | 14.0-<br>17.0 | 0.70** | 3.0** | 0.08** | 1.0** | 0.01** | P-0.025**<br>S-0.010** |

\*The undiluted deposited chemical composition of C-4 alloy covered electrodes has 0.015 percent maximum carbon, 0.20 percent maximum silicon and 1.5 percent maximum manganese.

\*\*Maximum

<sup>a</sup>As balance

# TYPICAL PHYSICAL PROPERTIES

| Physical Property                     | Temp., °F     | British Units                       | Temp., °C                    | Metric Units                             |
|---------------------------------------|---------------|-------------------------------------|------------------------------|--|
| Density                               | 68            | 0.312 lb/in. <sup>3</sup>           | 20                           | 8.64 g/cm. <sup>3</sup>                  |
| Electrical Resistivity                | 74            | 49.1 microhm-in.                    | 23                           | 1.25 microhm-m                           |
|                                       | 77            | 44.1 <sup>a</sup> microhm-in.       | 25                           | 1.12 <sup>a</sup> microhm-m              |
|                                       | 212           | 49.3 microhm-in.                    | 100                          | 1.25 microhm-m                           |
|                                       | 392           | 49.6 microhm-in.                    | 200                          | 1.26 microhm-m                           |
|                                       | 572           | 49.9 microhm-in.                    | 300                          | 1.27 microhm-m                           |
|                                       | 752           | 50.2 microhm-in.                    | 400                          | 1.28 microhm-m                           |
|                                       | 932           | 50.8 microhm-in.                    | 500                          | 1.29 microhm-m                           |
|                                       | 1112          | 51.8 microhm-in.                    | 600                          | 1.32 microhm-m                           |
| Mean Coefficient of Thermal Expansion | 68-200        | 6.0 microinches/in.-°F              | 20-93                        | 10.8 x 10 <sup>-6</sup> m/m-K            |
|                                       | 68-400        | 6.6 microinches/in.-°F              | 20-204                       | 11.9 x 10 <sup>-6</sup> m/m-K            |
|                                       | 68-600        | 7.0 microinches/in.-°F              | 20-316                       | 12.6 x 10 <sup>-6</sup> m/m-K            |
|                                       | 68-800        | 7.2 microinches/in.-°F              | 20-427                       | 13.0 x 10 <sup>-6</sup> m/m-K            |
|                                       | 68-1000       | 7.4 microinches/in.-°F              | 20-538                       | 13.3 x 10 <sup>-6</sup> m/m-K            |
|                                       | 68-1200       | 7.5 microinches/in.-°F              | 20-649                       | 13.5 x 10 <sup>-6</sup> m/m-K            |
|                                       | 68-1400       | 8.0 microinches/in.-°F              | 20-760                       | 14.4 x 10 <sup>-6</sup> m/m-K            |
|                                       | 68-1600       | 8.3 microinches/in.-°F              | 20-871                       | 14.9 x 10 <sup>-6</sup> m/m-K            |
| Thermal Conductivity                  | 74            | 70 Btu-in./ft. <sup>2</sup> hr.-°F  | 23                           | 10.1 W/m-K                               |
|                                       | 212           | 79 Btu-in./ft. <sup>2</sup> hr.-°F  | 100                          | 11.4 W/m-K                               |
|                                       | 392           | 92 Btu-in./ft. <sup>2</sup> hr.-°F  | 200                          | 13.2 W/m-K                               |
|                                       | 572           | 104 Btu-in./ft. <sup>2</sup> hr.-°F | 300                          | 15.0 W/m-K                               |
|                                       | 752           | 116 Btu-in./ft. <sup>2</sup> hr.-°F | 400                          | 16.7 W/m-K                               |
|                                       | 932           | 128 Btu-in./ft. <sup>2</sup> hr.-°F | 500                          | 18.4 W/m-K                               |
|                                       | 1112          | 142 Btu-in./ft. <sup>2</sup> hr.-°F | 600                          | 20.5 W/m-K                               |
|                                       | Specific Heat | 32                                  | 0.097 Btu/lb.-°F             | 0  |
| 212                                   |               | 0.102 Btu/lb.-°F                    | 100                          | 427 J/kg-K                               |
| 392                                   |               | 0.107 Btu/lb.-°F                    | 200                          | 448 J/kg-K                               |
| 572                                   |               | 0.111 Btu/lb.-°F                    | 300                          | 465 J/kg-K                               |
| 752                                   |               | 0.114 Btu/lb.-°F                    | 400                          | 477 J/kg-K                               |
| 932                                   |               | 0.117 Btu/lb.-°F                    | 500                          | 490 J/kg-K                               |
| 1112                                  |               | 0.120 Btu/lb.-°F                    | 600                          | 502 J/kg-K                               |
| Thermal Diffusivity                   |               | 74                                  | 0.004 in. <sup>2</sup> /sec. | 23                                       |
|                                       | 212           | 0.005 in. <sup>2</sup> /sec.        | 100                          | 3.1 x 10 <sup>-6</sup> m <sup>2</sup> /s |
|                                       | 392           | 0.005 in. <sup>2</sup> /sec.        | 200                          | 3.3 x 10 <sup>-6</sup> m <sup>2</sup> /s |
|                                       | 572           | 0.006 in. <sup>2</sup> /sec.        | 300                          | 3.7 x 10 <sup>-6</sup> m <sup>2</sup> /s |
|                                       | 752           | 0.006 in. <sup>2</sup> /sec.        | 400                          | 4.0 x 10 <sup>-6</sup> m <sup>2</sup> /s |
|                                       | 932           | 0.007 in. <sup>2</sup> /sec.        | 500                          | 4.3 x 10 <sup>-6</sup> m <sup>2</sup> /s |
|                                       | 1112          | 0.007 in. <sup>2</sup> /sec.        | 600                          | 4.7 x 10 <sup>-6</sup> m <sup>2</sup> /s |

a - specimens aged 16,000 hours at 1200°F (659°C.)

## AVERAGE DYNAMIC MODULUS OF ELASTICITY\*

| Form                              | Condition  | Test Temperature |      | Modulus of Elasticity |     |
|-----------------------------------|--|------------------|------|-----------------------|-----|
|                                   |  | °F               | °C   | 10 <sup>6</sup> psi   | GPa |
| Plate, 1/2 in.<br>(12.7 mm) thick | Heat-treated at<br>at 1950°F(1066°C)<br>rapid quench | Room             | Room | 30.8                  | 211 |
|                                   |  | 200              | 93   | 30.2                  | 207 |
|                                   |  | 400              | 204  | 29.3                  | 201 |
|                                   |  | 600              | 316  | 28.3                  | 194 |
|                                   |  | 800              | 427  | 27.3                  | 187 |
|                                   |  | 1000             | 538  | 26.2                  | 179 |
|                                   |  | 1200             | 649  | 25.0                  | 171 |
|                                   |  | 1400             | 760  | 23.7                  | 162 |
|                                   |  | 1600             | 871  | 22.2                  | 152 |
|                                   |  | 1800             | 982  | 20.6                  | 141 |

\*Average of three tests at each temperature.

## AVERAGE FORMABILITY

| Form                            | Condition   | Average Olsen Cup Depth,* |      |
|---------------------------------|---|---------------------------|------|
|                                 |   | in.                       | mm   |
| Sheet, 0.065 in. (1.7 mm) thick | Heat-treated at at 1950°F<br>(1066°C), rapid quench | 0.52                      | 13.2 |
|                                 | Aged 1000 hours at<br>1600°F (871°C)                | 0.52                      | 13.2 |

\*Average of five tests.

## AVERAGE OXIDATION DATA

| Test Temperature | Average Oxidation Rate<br>per 100-hour test period -<br>100 hours, intermittent* |      |       |      |    |
|------------------|--|------|-------|------|----|
|                  |  | °F   | °C    | mils | mm |
| 1900             | 1038   | 0.16 | 0.004 |      |    |

\*Four 25-hour periods. Cycled to room temperature after each period.

## AVERAGE HARDNESS AND TENSILE DATA, SHEET

| Form                            | Condition                                   | Test Temp. |      | Ultimate Tensile Strength |     | Yield Strength at 0.2% Offset |     | Elongation in 2 in (51mm) | Hardness Rockwell |
|---------------------------------|---|------------|------|---------------------------|-----|-------------------------------|-----|---------------------------|-------------------|
|                                 |   | °F         | °C   | Ksi                       | MPa | Ksi                           | MPa | %                         |                   |
| Sheet, 0.065 in. (1.7 mm) thick | Heat-treated at 1950°F(1066°C) rapid quench | Room       | Room | 111.4                     | 768 | 60.3                          | 416 | 52                        | B-90              |
|                                 |   | 400        | 204  | 102.4                     | 706 | 58.5                          | 403 | 49                        | -                 |
|                                 |   | 600        | 316  | 97.9                      | 675 | 53.8                          | 371 | 52                        | -                 |
|                                 |   | 800        | 427  | 95.2                      | 656 | 46.4                          | 320 | 64                        | -                 |
| Sheet, 0.125 in. (3.2 mm) thick | Heat-treated at 1950°F(1066°C) rapid quench | Room       | Room | 116.2                     | 801 | 61.0                          | 421 | 54                        | B-92              |
|                                 |   | 400        | 204  | 98.3                      | 678 | 46.4                          | 320 | 54                        | -                 |
|                                 |   | 600        | 316  | 97.5                      | 672 | 43.9                          | 303 | 59                        | -                 |
|                                 |   | 800        | 427  | 93.4                      | 644 | 43.9                          | 303 | 62                        | -                 |
|                                 |   | 1000       | 538  | 93.5                      | 645 | 43.4                          | 299 | 55                        | -                 |
|                                 |   | 1200       | 649  | 82.8                      | 571 | 42.2                          | 291 | 50                        | -                 |
| Sheet, 0.156 in. (4.0 mm) thick | Heat-treated at 1950°F(1066°C) rapid quench | Room       | Room | 113.5                     | 783 | 53.0                          | 365 | 55                        | B-91              |
|                                 |   | 400        | 204  | 99.9                      | 689 | 39.9                          | 275 | 55                        | -                 |
|                                 |   | 600        | 316  | 95.3                      | 657 | 36.1                          | 249 | 61                        | -                 |
|                                 |   | 800        | 427  | 95.1                      | 656 | 36.2                          | 250 | 68                        | -                 |

## AVERAGE TENSILE DATA, AGED SHEET AND PLATE

| Form                            | Condition                      | Test Temp. |      | Ultimate Tensile Strength |     | Yield Strength at 0.2% Offset |     | Elongation in 2 in (51mm) |
|---------------------------------|--------------------------------|------------|------|---------------------------|-----|-------------------------------|-----|---------------------------|
|                                 |                                | °F         | °C   | Ksi                       | MPa | Ksi                           | MPa | %                         |
| Sheet, 0.125 in. (3.2 mm) thick | Aged 100 hrs. at 1650°F(899°C) | Room       | Room | 114.6                     | 790 | 54.6                          | 376 | 56                        |
|                                 |                                | 400        | 204  | 103.2                     | 712 | 47.1                          | 325 | 54                        |
|                                 |                                | 600        | 316  | 99.5                      | 686 | 43.1                          | 297 | 57                        |
|                                 |                                | 800        | 427  | 97.0                      | 669 | 40.6                          | 280 | 60                        |
|                                 |                                | 1000       | 538  | 93.3                      | 643 | 39.9                          | 275 | 57                        |
|                                 |                                | 1200       | 649  | 86.6                      | 597 | 37.2                          | 256 | 56                        |
|                                 |                                | 1400       | 760  | 76.2                      | 525 | 36.3                          | 250 | 56                        |
| Plate, 3/8 in. (9.5 mm) thick   | Aged 100 hrs. at 1650°F(899°C) | Room       | Room | 111.8                     | 771 | 48.7                          | 336 | 62                        |
|                                 |                                | 400        | 204  | 100.6                     | 694 | 39.5                          | 272 | 51                        |
|                                 |                                | 600        | 316  | 98.0                      | 676 | 37.0                          | 255 | 56                        |
|                                 |                                | 800        | 427  | 97.2                      | 670 | 37.1                          | 256 | 57                        |
|                                 |                                | 1000       | 538  | 89.6                      | 618 | 32.1                          | 221 | 53                        |
|                                 |                                | 1200       | 649  | 89.6                      | 618 | 34.1                          | 235 | 56                        |
|                                 |                                | 1400       | 760  | 73.5                      | 507 | 29.7                          | 205 | 70                        |

## AVERAGE TENSILE DATA, PLATE AND WELDMENTS

| Form                                       | Condition   | Test Temp. |      | Ultimate Tensile Strength |     | Yield Strength at 0.2% Offset |     | Elongation in 2 in (51mm) |
|--|---|------------|------|---------------------------|-----|-------------------------------|-----|---------------------------|
|  |   | °F         | °C   | Ksi                       | MPa | Ksi                           | MPa | %                         |
| Plate, 1/4 in.<br>(6.3 mm) thick           | Heat-treated at<br>1950°F(1066°C)<br>rapid quenched | Room       | Room | 111.3                     | 767 | 48.8                          | 336 | 58                        |
|  |   | 400        | 204  | 104.0                     | 717 | 42.8                          | 295 | 54                        |
|  |   | 600        | 316  | 103.3                     | 712 | 40.8                          | 281 | 55                        |
|  |   | 800        | 427  | 99.0                      | 683 | 37.0                          | 255 | 60                        |
| Plate, 3/8 in.<br>(9.5 mm) thick           | Heat-treated at<br>1950°F(1066°C)<br>rapid quenched | Room       | Room | 114.7                     | 791 | 51.6                          | 356 | 59                        |
|  |   | 400        | 204  | 105.4                     | 727 | 43.6                          | 301 | 56                        |
|  |   | 600        | 316  | 102.1                     | 704 | 39.1                          | 270 | 59                        |
|  |   | 800        | 427  | 96.3                      | 657 | 37.4                          | 258 | 62                        |
|  |   | 1000       | 538  | 93.3                      | 643 | 33.0                          | 228 | 52                        |
|  |   | 1200       | 649  | 84.7                      | 584 | 31.5                          | 217 | 52                        |
| Plate, 1/2 in.<br>(12.7 mm) thick          | Heat-treated at<br>1950°F(1066°C)<br>rapid quenched | Room       | Room | 116.8                     | 805 | 48.6                          | 335 | 63                        |
|  |   | 200        | 93   | 110.9                     | 765 | 43.7                          | 301 | 70                        |
|  |   | 400        | 204  | 105.2                     | 725 | 38.3                          | 264 | 61                        |
|  |   | 600        | 316  | 102.5                     | 707 | 35.8                          | 247 | 65                        |
|  |   | 800        | 427  | 99.8                      | 688 | 34.2                          | 236 | 66                        |
|  |   | 1000       | 538  | 92.1                      | 635 | 29.8                          | 205 | 71                        |
| Welded Plate,<br>1/2 in.<br>(12.7mm) thick | As-welded*  | Room       | Room | 112.7                     | 777 | 68.3                          | 471 | 40                        |
|  |   | 500        | 260  | 94.9                      | 654 | 51.0                          | 352 | 39                        |
|  |   | 1000       | 538  | 87.3                      | 602 | 48.7                          | 336 | 35                        |
| Welded Plate,<br>1/2 in.<br>(12.7mm) thick | Aged at 1200°F<br>(649°C) for:                      | Room       | Room | 113.7                     | 784 | 62.2                          | 429 | 48                        |
|  |   | Room       | Room | 118.7                     | 818 | 59.6                          | 411 | 46                        |
|  |   | Room       | Room | 107.1                     | 738 | 71.4                          | 492 | 42                        |
| All-Weld Metal                             | As-welded*  | Room       | Room | 107.1                     | 738 | 71.4                          | 492 | 42                        |

\*As gas tungsten arc welded.

## AVERAGE CORROSION DATA\*

| Media             | Concentration,<br>percent by<br>weight | Temp.,  |    | Average Corrosion Rate, mils (mm) per year |      |              |      |          |      |
|-------------------|--|---------|----|--|------|--------------|------|----------|------|
|                   |  | °F      | °C | Unwelded**                                 |      | As-welded*** |      | Aged**** |      |
|                   |  |         |    | mils                                       | mm   | mils         | mm   | mils     | mm   |
| Formic Acid       | 20                                     | Boiling |    | 2.9  | 0.07 | 3.5          | 0.09 | 3.5      | 0.09 |
| Hydrochloric Acid | 10                                     | 167     | 75 | 36.0                                       | 0.91 | 34.0         | 0.86 | 35.0     | 0.89 |
| Nitric Acid       | 10                                     | Boiling |    | 5.9  | 0.15 | 7.1          | 0.18 | 9.2      | 0.23 |
| Phosphoric Acid   | 85                                     | Boiling |    | 61.0                                       | 1.5  | 52.0         | 1.30 | 85.0     | 2.20 |
| Sulfuric Acid     | 10                                     | Boiling |    | 22.0                                       | 0.56 | 25.0         | 0.64 | 20.0     | 0.51 |
| Sulfuric Acid     | 85                                     | 167     | 75 | 23.0                                       | 0.58 | 17.0         | 0.43 | 21.0     | 0.53 |

\*Determined in Laboratory tests. It is recommended that samples be tested under actual plant conditions.

\*\* Heat-treated at 1959°F (1066°C), water quenched.

\*\*\* Gas tungsten arc welded.

\*\*\*\* Aged 100 hours at 1650°F (899°C)

# ACCELERATED QUALITY CONTROL CORROSION TESTS

Accelerated tests may be used to assess the overall corrosion resistance of C-4 alloy. Such tests are conducted in an aggressive environment which is considerably more severe than that usually encountered in industrial processes.

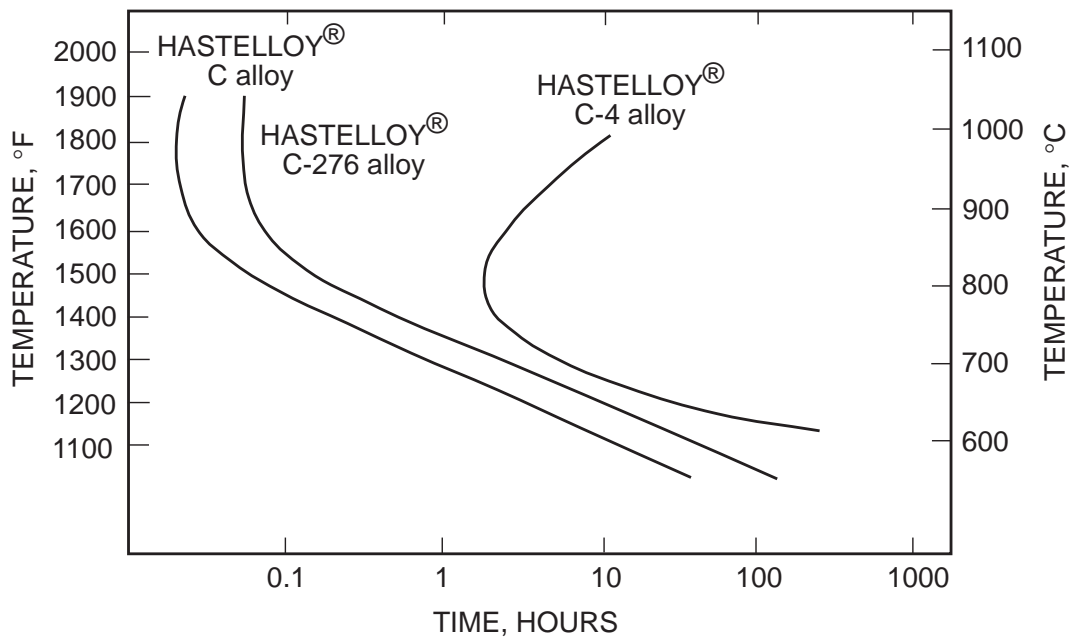
*Ferric Sulfate Test*-Specimens are tested for one 24-hour period in accordance with ASTM G-28A (boiling 50 percent sulfuric acid with 42 grams per liter of ferric sulfate). The presence of grain boundary precipitates results in an

accelerated corrosion attack. Typical corrosion rates for C-4 alloy are shown in the following table.

| Type of Test | Average Corrosion Rate, per year |     |             |     |         |     |
|--------------|----------------------------------|-----|-------------|-----|---------|-----|
|              | Unwelded*                        |     | As-welded** |     | Aged*** |     |
|              | mils                             | mm  | mils        | mm  | mils    | mm  |
| ASTM G-28A   | 100                              | 2.5 | 111         | 2.8 | 114     | 2.9 |

- \* Solution heat-treated
- \*\* Gas tungsten arc welded.
- \*\*\* Aged 100 hours at 1650°F (899°C)

**Relationship of Time and Temperature to Beginning of Precipitate in Ni-Mo-Cr Corrosion Alloys**



# STRESS CORROSION

Stressed specimens were tested in a solution of boiling 42 percent magnesium

chloride representing an accelerated chloride stress-corrosion cracking test. C-4

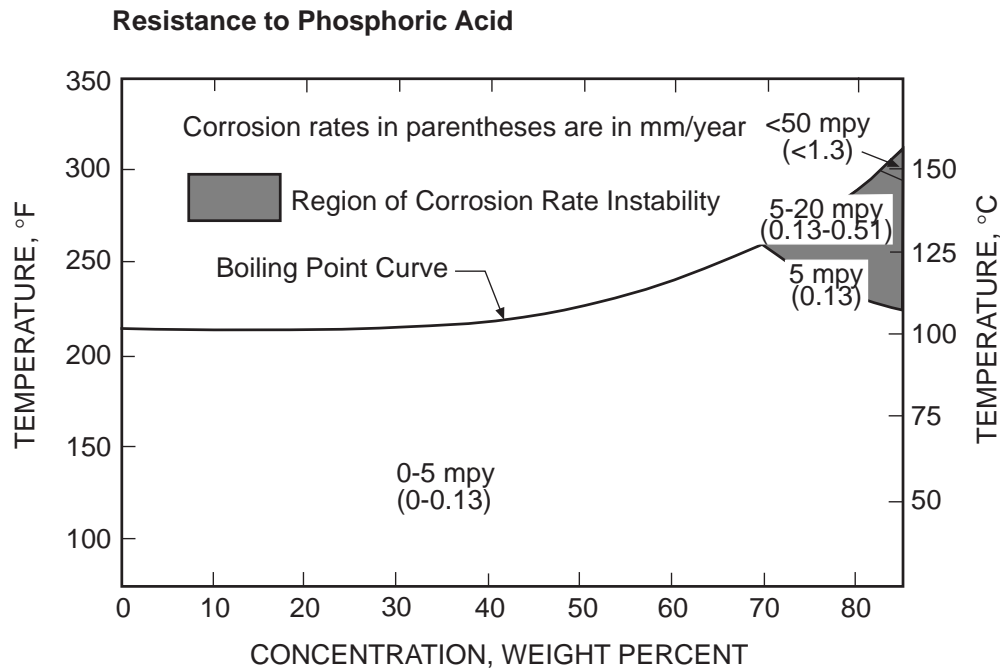
alloy went over 1000 hours without cracking.

# ISOCORROSION DIAGRAMS\*

The isocorrosion diagrams shown on this and subsequent pages were plotted using data

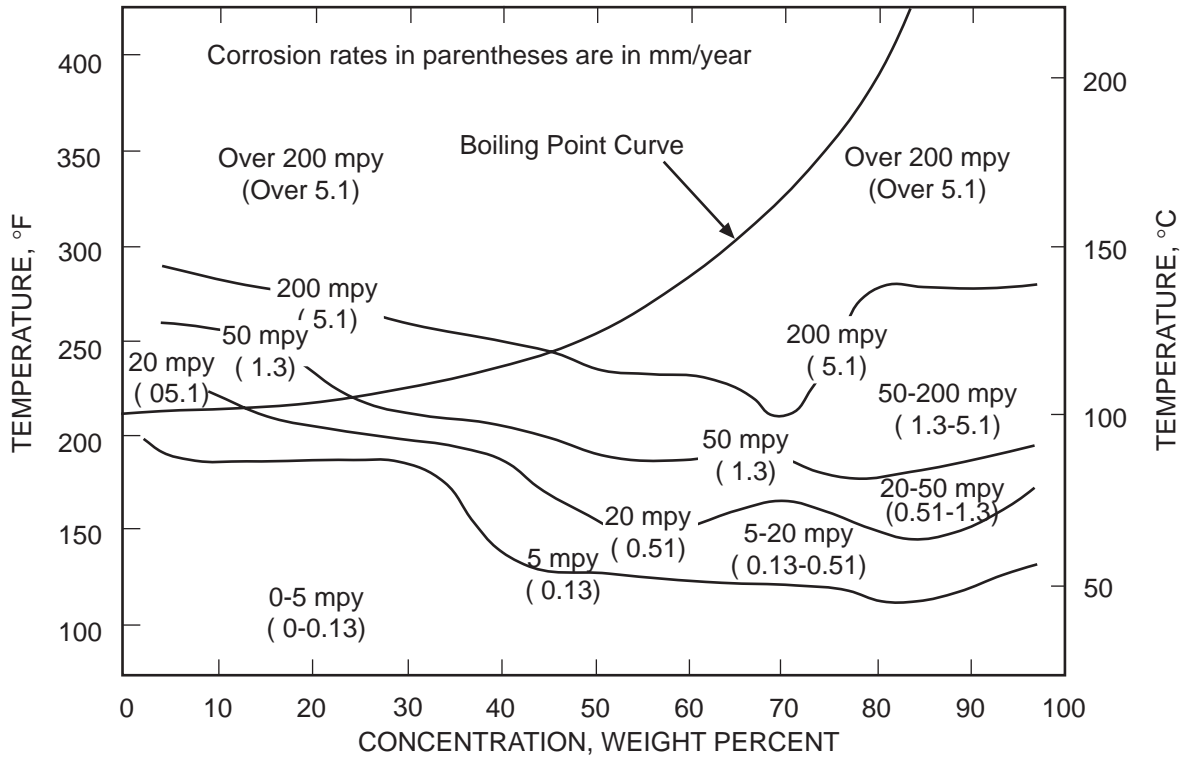
obtained in laboratory test in reagent grade acids. These data should be used only as

a guide. It is recommended that samples be tested under actual plant conditions.

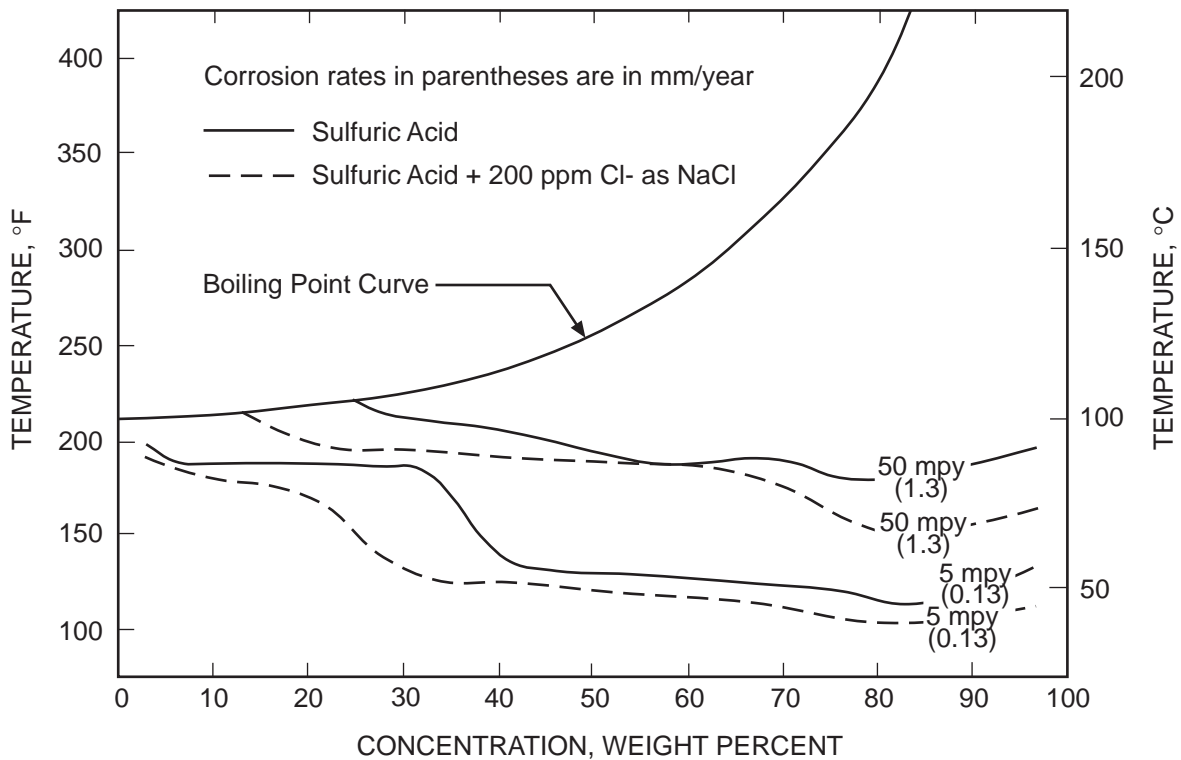


\*All test specimens were solution heat-treated at 1950°F (1066°C), rapid quench and in the unwelded condition.

### Resistance to Sulfuric Acid

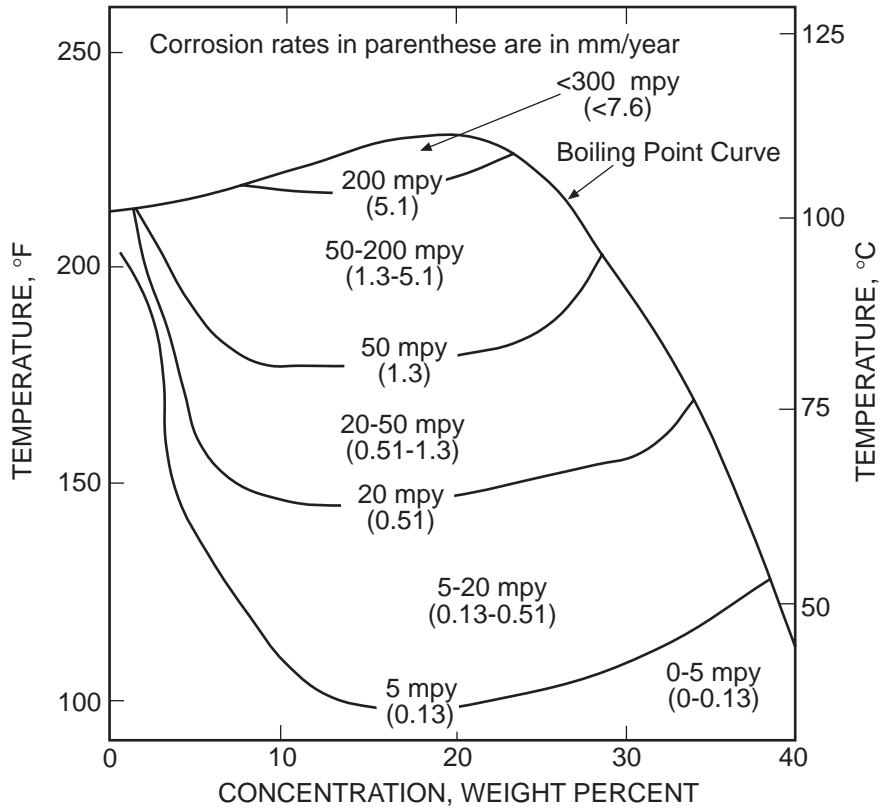


### Resistance to Sulfuric Acid with 200 ppm Chloride Ions

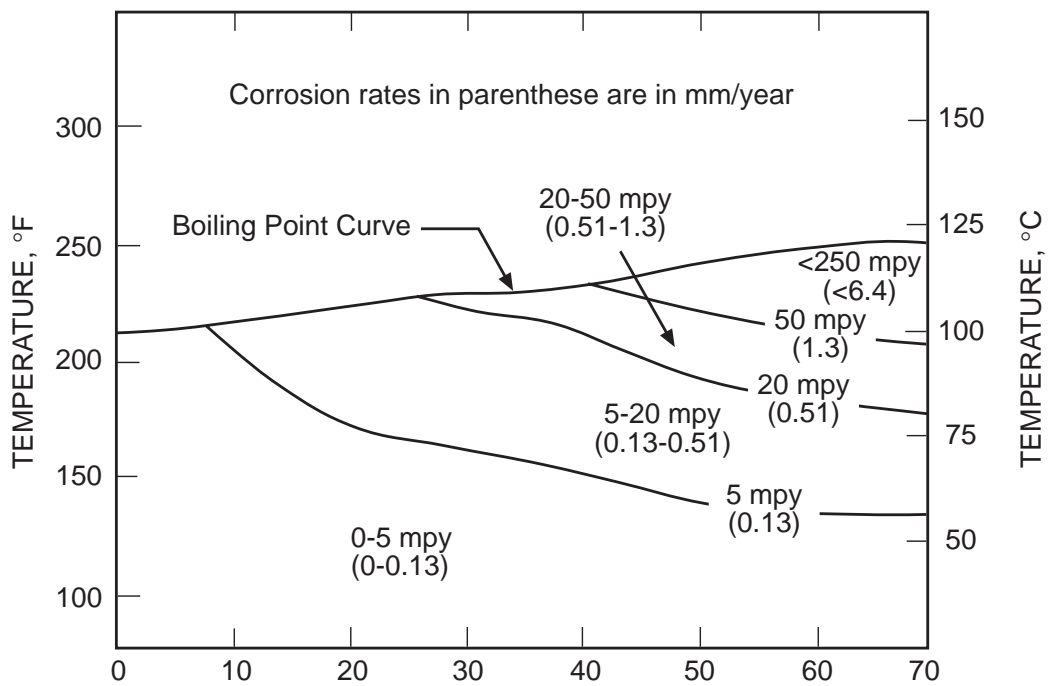




### Resistance to Hydrochloric Acid



### Resistance to Nitric Acid



# STANDARD PRODUCTS

By Brand or Alloy Designation:

# HAYNES

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**International**

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## HASTELLOY® Family of Corrosion-Resistant Alloys

B-2, B-3®, C-4, C-22®, C-276, C-2000®, D-205™, G-3, G-30®, G-35™, G-50®, and N

## HASTELLOY Family of Heat-Resistant Alloys

S, W, and X

## HAYNES® Family of Heat-Resistant Alloys

25, R-41, 75, HR-120®, HR-160®, 188, 214™, 230®, 230-W™, 242™, 263, 556™, 617, 625, 65SQ®, 718, X-750, MULTIMET®, and Waspaloy

## Corrosion-Wear Resistant Alloy

ULTIMET®

## Wear-Resistant Alloy

6B

## HAYNES Titanium Alloy Tubular

Ti-3Al-2.5V

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### Standard Forms:

Bar, Billet, Plate, Sheet, Strip, Coils, Seamless or Welded Pipe & Tubing, Pipe Fittings, Flanges, Fittings, Welding Wire, and Coated Electrodes

### Properties Data:

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